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JPRS L/9302

17 September 1980

USSR Report

MATERIALS SCIENCE AND METALLURGY

(FOUO 5/80)



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ANALYSIS AND TESTING

ADVANCED KNOW-HOW IN NONDESTRUCTIVE QUALITY CONTROL OF WELDED JOINTS

Kiev PEREDOVY OPYT NERAZRUSHAYUSHCHEGO KONTROLYA KACHESTVA SVARNYKH SOYEDINENIY (Advanced Know-How in Nondestructive Quality Control of Welded Joints) in Russian 1979 pp -, 137-138

[Annotation and table of contents from collection of articles edited by Doctor of Technical Sciences V. A. Troitskiy et al, Izdatel'stvo IES imeni Ye. O. Patona AN USSR, 140 pages]

[Text] This collection presents the results of research and development on fundamental methods and means of nondestructive quality control of welded joints, as applied to various kinds of welded constructions.

This collection is intended for scientific and engineering and technical personnel working on problems of internal flaw detection and welding.

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CORROSION

CATHODIC PROTECTION OF SEA VESSELS AND STRUCTURES FROM CORROSION

Leningrad PROTEKTORNAYA ZASHCHITA MORSKIKH SUDOV I SOORUZHENIY OT KORROZII
in Russian 1979 pp 3-4, 185-186

[Foreword and table of contents from book by Ye.Ya. Lyublinskiy, Izdatel'stvo Sudostroyeniye, 188 pages]

[Text] Foreword

Cathodic protection is one of the most widespread variations of the electrochemical method of protecting vessels from corrosion. At the present time more than half of all sea vessels and metal structures have cathodic protection. Each year its pace and extent of introduction increase, and it has found application both as an independent method of suppressing corrosion and in combination with paint and lacquer coatings.

The wide use of cathodic protection is explained by its high technical and economic effectiveness, availability, simplicity and reliability in the process of the utilization of vessels. During the extent of its entire service life, which can be selected to equal any length (from one year to 20 years and more), cathodic protection does not require maintenance.

The state of the art of cathodic protection technology makes it possible to increase considerably the profitability of sea vessels and metal structures, since it affords the following possibilities:

An increase in the length of operating periods between docking (between repairs).

An increase in the amount of freightage as the result of a reduction in the number of dockings and their duration.

A reduction in the labor intensiveness, length and cost of work associated with eliminating the aftereffects of corrosion and carrying out means of protection from it.

An increase in the reliability and service life of paint and lacquer coatings when using combined means of protection.

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The elimination or significant reduction in the amount of highly labor intensive cleaning and painting work; for example, in protecting from corrosion the inner surface of ballast tanks, compartments, confined spaces and nearly inaccessible surfaces.

- However, achievement of the high technical and economic effectiveness of cathodic protection is possible only with the proper selection of the material, design, and type size of sacrificial anodes and the protection system, as well as with knowledge of the design rules and with strict observance of the technology for the installation, removal and restoration of sacrificial anodes.

The technical level of cathodic protection is determined by achievements in the area of creating sacrificial anode alloys and sacrificial anodes. Therefore, the major objectives have been a systematization and analysis of data on these questions and the presentation of specific recommendations on the utilization of cathodic protection taking into account the diversity of conditions for the utilization of sea vessels and structures. This approach to presentation of the material is due to the small size of this edition and can be justified, since in recent years a number of books [6, 12, 14, 24, 43, 46, 56] have been published almost simultaneously, extensively elucidating the theoretical fundamentals of electrochemical corrosion and the protection of metals.

This is the first time a book has been published which contains only questions relating to cathodic protection. Up to the present time there has not been a monograph generalizing the extensive scientific and practical developments in this field, which began to be developed mainly at the end of the 40's. Therefore, in this edition practical recommendations are given, based on an analytical discussion of some of the most important research results.

The above-mentioned also determined the structure of the book. Each chapter contains concise results of theoretical or experimental investigations and substantiated technical requirements for cathodic protection systems which can be recommended for practical purposes.

In the first chapter are given the most general notions regarding the mechanism of corrosion and electrochemical protection, data on the rate of corrosion of shipbuilding metals are generalized, and recommendations are given on the parameters for the protection of these metals. The data in the first chapter can be useful in estimating the danger of corrosion, in establishing criteria for immunity and in selecting protection parameters.

The second chapter is devoted to the central question determining the technical level of cathodic protection--to a generalization and analysis of the results of investigations of the kinetics and mechanism of the anodic dissolution of metal systems based on magnesium, aluminum, zinc and

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manganese, and to selection of the optimal composition of sacrificial anode alloys. The most important information is presented on methods of the commercial fabrication of sacrificial anodes which ensure high and stable characteristics for them.

For the purpose of a differentiated approach to the creation and application of cathodic protection, in the third chapter for the first time a comparatively extensive analysis is made of the influence of a diversity of factors, characterized by the conditions of and regions of the utilization of sea vessels and structures, on the key working characteristics of sacrificial anode alloys. The data presented make it possible to create an optimal system of cathodic protection.

The fourth and fifth chapters contain material required by planning, ship-building, ship repairing and operating organizations and enterprises for the purpose of selecting, designing, installing and utilizing cathodic protection.

The information presented in the sixth chapter can be useful for selecting the most efficient and economically advantageous system of cathodic protection.

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CORROSION OF ZINC AND LEAD IN SULFURIC ACID SOLUTIONS

Alma-Ata KORROZIYA TSINKA I SVINTSA V SERNOKISLYKH RASTVORAKH (Corrosion of Zinc and Lead in Sulfuric Acid Solutions) in Russian 1979

[Annotation, foreword and table of contents from book by Kir'yakov, G. Z.; Bryntseva, V. I., Nauka, 72 pages]

[Text] Annotation

This monograph considers the results of investigations of corrosion of zinc and lead in sulfuric acid solutions in the presence of admixtures of cobalt, copper and antimony salts, and surface-active additives. A relationship has been shown between the speed of zinc corrosion and the magnitude of the cathodic surface formed as a result of the cementation of the admixture metals. The role of the phase layer in the corrosion process was established.

A classification is given of organic surface-active substances according to the mechanism of their action on the corrosion processes.

The book is intended for chemists in scientific research establishments and plant laboratories, as well as for use as a manual for selecting surface-active substances to protect metals against corrosion.

Sixteen illustrations, 3 tables, bibliography of 155 items.

Foreword

The rapid development of scientific knowledge about corrosion and the protection of metals is connected with the rapid growth of technology. Seemingly faultlessly substantiated concepts about corrosion mechanisms change; traditional methods for metal protection are improved, and new ones are being created.

The use of corrosion inhibitors for protection originated comparatively recently. Not pretending to universality, in many cases, it is the single possible method for protecting metals from rapid destruction.

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In this monograph, investigations are correlated on corrosion and the protection of zinc and lead made in the Electrochemical Laboratory of the IOKE [expansion unknown] AN Kazakh SSR for a number of years. Many papers have been published in periodicals. However, their dispersion in many places has made them inaccessible and, moreover, the understanding of the essence of the processes occurring in corrosion has changed. In the conditions considered, processes occur on an inhomogeneous surface to which are related catalytic processes that accompany electrochemical reactions. The authors of the monograph have made an attempt to explain the electrode reactions, taking into account the electrochemical and catalytic process stages. This approach made it possible to determine several special features of the action of surface-active substances on the processes occurring during the corrosion of zinc and lead.

From the time of De la Rive, investigations about corrosion have been based on concepts about local components. It is precisely on their bases that such practical methods as the cathodic and protector methods for protecting metal structures were developed.

At present, the theory of local components is being subjected to sharp criticism. However, in many cases of corrosion, it was established unambiguously that cathodic and anodic processes occur in spatially separated sections of the heterogeneous surface. With certain precautions, the theory of local components may be used.

The first chapter of this monograph describes the modern state of the art. In the literature on corrosion, organic surface-active compounds that intensify corrosion processes are called stimulators (inhibitors) of corrosion.

Based on the fact that an insignificant amount of organic additives stimulates corrosion processes, it may be assumed that these reactions have a catalytic nature.

In clarifying the mechanism of elementary acts of the catalytic processes, quantum-statistical and quantum-dynamic investigation methods are used widely.* However, these investigations apply to condensation systems and reactions with the participation of complex molecules and are considered in the process of transition from reagents to products of the system. In the given corrosion processes as in pure solutions, as well as in solutions containing surface-active substances, the final product of the electrochemical reaction is in hydrogen. On the basis of the clarified mechanisms of proceeding reactions, and the structure of organic compounds, it may be assumed that the process of the proton transfer from the solution to the surface of the electrode proceeds in one stage, since the transfer from the initial state to the final may be continuously dynamic.

*R. R. Dogonadze, A. M. Kuznetsov. "ELEKTROKIMIYA," 1977, v. 12, No 5, p 672; Summaries of Science and Technology. "Fiz. khimiya, kinetika," 1973, v. 11, No 1.

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There is no single opinion on the role of the phase layer in corrosion processes. It has been shown on the example of lead that the phase layer of corrosion products may inhibit corrosion processes. Moreover, it has been established that in this case also the surface-active substances participate effectively in corrosion processes. The mechanisms of PAV [Surface-active substances] action, noted on zinc, are also clearly demonstrated on the surface of lead. Therefore, the special features of the action of surface-active substances are specific not only for zinc, but are general for corrosion processes.

The authors are very grateful to reviewers Ya. A. Dorfman, doctor of chemical sciences, and S. P. Bukhman, candidate of chemical sciences, as well as A. B. Fasman, scientific editor and doctor of chemical sciences, for their detailed and favorable critical analysis of the manuscript.

The authors express their sincere gratitude to academicians of the AN Kazakh SSR, D. V. Sokol'skiy, for valuable advice and useful criticisms.

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TITANIUM

MODERN STRUCTURAL TITANIUM ALLOYS

Moscow METALLOVEDENIYE I TERMICHESKAYA OBRABOTKA METALLOV in Russian No 7, Jul 80 pp 29-34

[Article by V. N. MOISEYEV]

[Text] High requirements are set forth for structural titanium. They should possess adequate strength and heat resistance, good thermal stability, i.e., the capacity to retain constant or slightly variable physical and mechanical properties after extended heating at operating temperatures and stresses, to have adequate ductility at deformation temperatures, good weldability, etc.

As analysis of our research and existing literature data showed that titanium alloys satisfy these requirements to the greatest degree where their structure is a mixture of alpha- and beta-solid solutions.

The number of elements which form wide concentrated regions of solid solutions with alpha- or beta-titanium is limited. Most of the elements, presenting practical interest, dissolve insignificantly in alpha-titanium. Exceptions are those elements such as oxygen, nitrogen, and aluminum which effectively strengthen alpha-titanium, or zirconium, hafnium, tin, tantalum and others which strengthen it to an insignificant degree. The tensile strength of binary and more complex titanium alloys, being alpha-solid solutions, is around 90-95 kgf/mm². Oxygen and nitrogen form stronger solid solutions with titanium, but the ductility of these solid solutions is low so that the content of oxygen and nitrogen is limited, as a rule, to 0.15-1.20% and 0.05-0.10% respectively.

An even smaller number of elements form beta-solid solutions with titanium over a wide concentration region; elements isomorphous to beta-titanium--Mo, V, Nb, Ta--form a continuous series of beta-solid solutions. The eutectoid-forming elements (Fe, Cr, Mn, Co, Ni, etc.) in conjunction with the slow occurrence of the eutectoid transformation under certain conditions can be used to stabilize the beta-phase, although these solid solutions are limitedly stable. The strength of beta-solid solutions can be as high as 100-105 kgf/mm².

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The fundamental principles of mechanical property change in titanium alloys, constituting mixtures of alpha- and beta-solid solutions, in the stabilized, thermally strengthened and cold-hardened states, are shown in Figure 1 and can be reduced to the following.

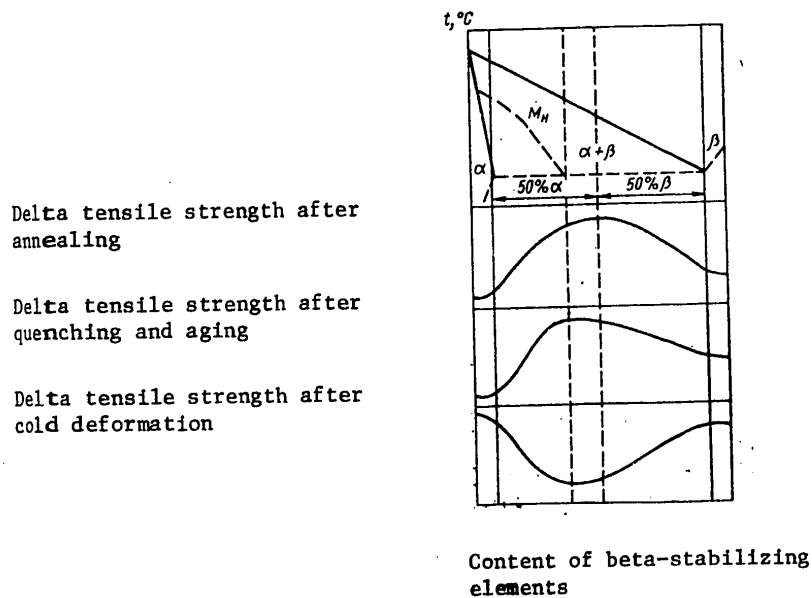


Fig. 1. Change of titanium alloy tensile strength after different treatments in relation to the content of beta-stabilizing elements.

The strength of two-phase alpha+beta-titanium alloys in an equilibrium (annealed) state depends on the strength of the coexisting alpha- and beta-solid solutions as well as on the degree of structure heterogeneity, i.e., on the quantitative ratio of alpha- and beta-phases in the alloy. Upon increasing the content of beta-phase in the alpha-matrix the rise in strength after annealing is increased, as manifested by the heterogenized structure. It reaches a maximum when the volume of alpha- and beta-phases is the same. This has been associated with the increase in the extent of alpha- and beta-phase interface boundary, which is a barrier for dislocation movement. Upon increasing the beta-phase content above 50%, strength rise after annealing is diminished (Fig. 1).

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For thermally hardenable alpha+beta-titanium alloys with a critical concentration of beta-stabilizing elements the effect of strengthening, which can be produced by quenching with subsequent aging, grows. The effect of strengthening as a result of heat treatment was maximum for alloys of critical composition. The increase in content of beta-stabilizing elements in alloys of subcritical composition is accompanied by a decrease in the growth of strength achieved as the result of quenching and aging (Fig. 1). The nature of the change in the strengthening effect was associated with the increase of metastable beta-phase volume, undergoing dispersion decomposition during aging, according to the degree of approximating their composition to the critical and with diminishment of its volume upon increasing the content of beta-stabilizing elements in alloys of subcritical composition.

The relationship of the strengthening effect in alpha+beta-alloys to the content of beta-stabilizing elements during cold strain can be described by the curve with a minimum (Fig. 1), where the greatest effect can be observed for single-phase alpha- and beta-alloys, and the least effect--for alpha+beta-alloys.

A small strengthening effect during cold deformation of alpha+beta-titanium alloys was caused by the alpha+beta-transformation occurring during deformation.

In titanium alloys with supersaturated alpha- and beta-solid solutions, under certain conditions, the formation of intermetallide compounds is possible; as a rule, those compounds increase strength very little and substantially lower ductility.

The formation of ordered alpha-phase of the Ti_3Al type in titanium alloys has special significance since aluminum as an alloying additive is put into the composition of almost all industrial alloys. The solubility of aluminum in alpha-titanium is decreased upon increasing the content of beta-stabilizing elements. This principle has been presented in Fig. 2 as an example of alloys in the Ti-Al-Mo system.

Most transition elements (Fe, Cr, Mn, Ni, etc.) dissolve very little in alpha-titanium, but with beta-titanium they form a very wide region of solid solutions which decompose by a eutectoid reaction with formation of the alpha-solid solution and an intermetallide constituent. The effect of temperature and heating duration on phase composition of titanium alloys with a varying content of eutectoid-forming elements is shown in Fig. 3 for alloys of the Ti-Fe system.

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Fig. 2. Solubility of aluminum in alpha-titanium in relation to molybdenum content in the alloy

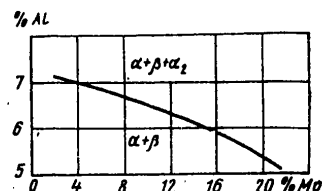
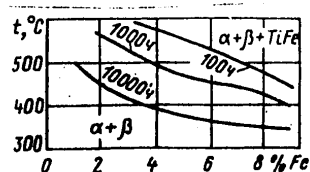


Fig. 3. Position of the interface boundary of alpha+beta/alpha + beta+TiFe in relation to heating time (hours) (numbers on the curves) and iron content in the alloy.

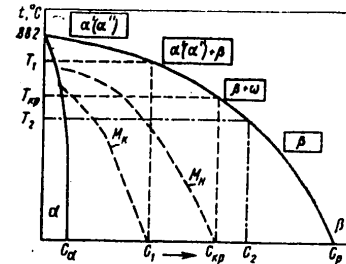


The features of titanium alloys containing eutectoid-forming elements must be considered when these alloys are used for extended periods at elevated temperatures.

Phase transformations, occurring during cooling, have a large effect on the properties of structural alpha+beta-titanium alloys. In titanium alloys with a relatively small concentration of beta-stabilizing elements there occurs, upon rapid cooling, a martensitic beta- to alpha'-phase transformation having a hexagonal crystal lattice. With increased content of beta-stabilizing elements the formation of the alpha"-phase is possible in a number of alloys during quenching which differ by a lower symmetry of the crystal lattice approximating a rhombic structure. Upon further alloying the metastable beta-phase with a cubic lattice is preserved in the alloy after hardening. In alloys with the content of beta-stabilizing elements somewhat exceeding the critical content, formation of the omega-phase, coherent with the matrix and having a hexagonal lattice, is possible. Structural transformations during hardening, occurring in titanium alloys with a varying content of beta-stabilizing elements, can be presented in the form of a generalized phase diagram "titanium--beta-stabilizing element" as shown in Fig. 4.

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Fig. 4. Ti-beta-stabilizing element phase diagram illustrating transformations during hardening. Solid lines--stable transformations, dash lines--metastable transformations.



Content of beta-stabilizing element.

Alpha- and beta-titanium alloys can be divided into four groups according to the nature of change in phase composition.

In the first group we find alloys with a concentration of beta-stabilizing elements up to C_1 , i.e., alloys which have a complete α' (α'') structure after quenching from the beta-region. After hardening of these alloys from the temperatures of the $\alpha+\beta$ -region in the interval from $\alpha+\beta \rightarrow \beta$ -transformation temperature down to T_1 their structure becomes a mixture of α' - α -phases, from T_1 to T_{cr} --a mixture of $\alpha'+\alpha+\beta$ -phases and below T_{cr} -- $\alpha+\beta$ structure.

Alloys in the second group have alloying element concentrations from C_1 to C_{cr} where the martensite transformation is not complete upon quenching from the beta-region, and their structure is a mixture of α' and β -phases. Alloys of this group, after quenching from the $\alpha+\beta \rightarrow \beta$ -transformation temperatures down to T_{cr} , have an $\alpha'+\alpha+\beta$ -structure, and from temperatures below T_{cr} --an $\alpha+\beta$ -structure.

In alloys of the third group with concentrations of beta-stabilizing elements from C_{cr} to C_2 , a portion of the β -phase is transformed into the ω -phase upon quenching from temperatures of the β -region or temperatures of the $\alpha+\beta \rightarrow \beta$ -transformation down to T_2 . Alloys of this group have an $\alpha+\beta$ -structure after quenching from temperatures below T_2 .

After quenching, alloys of the fourth group from temperatures above the $\alpha+\beta \rightarrow \beta$ -transformation temperature have an exclusively β -structure, and from temperatures below the $\alpha+\beta \rightarrow \beta$ -transformation --a $\beta+\alpha$ structure.

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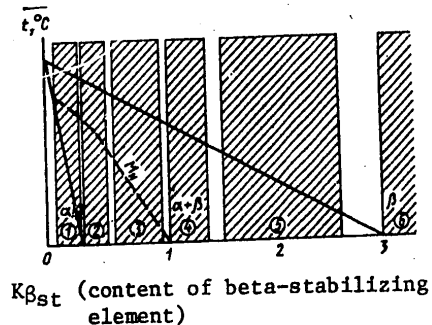
The metastable structure constituents--alpha'-, alpha"-, omega- and beta-phases--influence the physical, mechanical, operational and technological properties of alloys. This influence is especially noted in hot-worked titanium alloys such as those which have been heat or pressure treated, welded, etc.

The structural features of alpha+beta-titanium alloys, examined above in stable and metastable states were arranged in the order of alpha-alloys, pseudo-alpha-alloys, alpha+beta-alloys of the martensite class, transition alloys, pseudo-beta-alloys and beta-alloys which differ in their physical and mechanical properties and nature of phase transformations.

In order to classify an alloy according to chemical stabilization ($K_{\beta st}$) which can be determined as the ratio of the actual amount of beta-stabilizing elements in the alloy to its critical content (1). Classification of structural titanium alloys, their chemical composition and mechanical properties are presented in the table. The positioning of industrial titanium alloys is schematically shown in the "titanium--beta-stabilizing element" phase diagram in Fig. 5.

Titanium alpha-alloys are distinguished by high thermal stability, good weldability and an absence of cold-shortness. Their shortcomings are reduced ductility at equal strength for alpha+beta-alloys and a low ductility for alloys of average and higher strength. These alloys cannot be strengthened by heat treating.

Fig. 5. Positioning of industrial titanium alloys of different classes on the Ti-beta-stabilizing element phase diagram: 1--alpha alloys; 2--pseudo-alpha alloys; 3--alpha+beta-alloys of the martensite class; 4--alpha+beta-alloys of the transition class; 5--pseudo-beta-alloys; 6--beta alloys



Pseudo-alpha-titanium alloys are heterogeneous alpha-titanium alloys with a small quantity of beta-phase (2-6%) and a $K_{\beta st} < 0.25$. This makes it possible, by preserving the advantages of alpha-alloys, to partially remove their short-

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Table

(a) Класс сплавов	(b) $K_{\beta \text{ ст}}$	(c) Марка сплава	(d) Содержание элементов	(e) σ_B , кгс/мм ²	δ_s Ψ %	α_1 , кгс/см ² Xм/см ²	(f)
(i) не менее							
(г) α -сплавы	—	BT1-00. BT1-0 BT5 BT5-1 4200*	Нелегированный титан (h) То же (j) 5% Al 5% Al; 2,5% Sn 0,5% Pd	30—45 40—55 75—90 80—100 38—58	25 20 10 10 20	55 50 25 25 50	12 10 5 4 10
(к) Псевдо- α -сплавы	<0,25	OT4-0 OT4-1 OT4 AT2 AT3 BT20 TC5	0,8% Al; 0,8% Mn 1,5% Al; 1,0% Mn 3,5% Al; 1,5% Mn 2,0% Zr; 1,0% Mo 3,0% Al; 1,5% Σ (Fe, Cr, Si, B) 6% Al; 2% Zr; 1% Mo; 1% V 5% Al; 2% Zr; 3% Sn; 2% V	50—65 60—75 70—90 60—75 75—90 95—110 95—115	20 15 11 16 12 10 10	45 35 30 40 35 25 25	7 4,5 4 4 6 4 3,5
(л) $\alpha + \beta$ -сплавы мартенситного класса	0,3—0,9	BT6 BT14 BT16 BT23 BT3-1	6% Al; 4% V 4,5% Al; 3% Mo; 1% V 2,5% Al; 5% Mo; 5% V 5% Al; 2,5% Mo; 4,5% V; 1% Cr; 0,5% Fe 6% Al; 2,5% Mo; 2% Cr; 0,3% Si; 0,5% Fe	92—107/110 90—107/112 83—9/105—125 105—120/125 100—125/120	10/6 10/6 16/12 10/6 10/6	30/20 35/12 60/80 30/18 30/16	4/3 5/2,5 —/— 4/2,5 3/2
(м) $\alpha + \beta$ -сплавы переходного класса	1,0—1,4	BT22 BT30*	5% Al; 5% Mo; 5% V; 1% Fe; 1% Cr 11% Mo; 6% Sn; 4% Zr	110—125/130 80—90/120	9/6 12/5	25/16 45/15	3/2 5/2,5
(н) Псевдо- β -сплавы	1,6—2,4	BT15* TC6 BT32*	3% Al; 7% Mo; 11% Cr 3% Al; 5% Mo; 6% V; 11% Cr 2% Al; 8% Mo; 8% V; 1% Fe; 1% Cr	85—100/125 85—100/125 80—95/120	12/4 12/5 15/6	40/14 45/15 50/20	3,5/2 4/2 4,5/2,5
(о) β -сплавы	2,5—3,0	4201*	33% Mo	80—95	10	30	—

*Experimental and experimental-industrial alloys.

Remark. Properties of annealed samples cut from 60-mm and smaller rod are presented in the numerator while properties of quenched and aged samples are in the denominator.

Key: a--Alloy class
b-- $K_{\beta \text{ ст}}$
c--Alloy grade
d--element content
e--Tensile strength, kgf/mm²
f--Impact strength, kgf x m/cm²
g--Alpha-alloys
h--Unalloyed Ti
i--Minimum
j--Ditto
k--Pseudo-alpha-alloys
l--Alpha+beta-alloys of the martensite class
m--Alpha+beta-alloys of the transition class
n--Pseudo-beta-alloys
o--Beta-alloys

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comings. The technological ductility of pseudo-alpha-alloys, owing to the presence of some beta-phase, is noticed by higher, which allows them to be used without having to undergo sure treatment. Alloys of this class possess good weldability and an adequately high stability. Small parts can be somewhat strengthened by quenching and aging. However a strengthening heat treatment of these alloys has not found an industrial application. A different level of strength of these alloys can be mainly achieved by alloying the alpha-solid solution using, as a rule, aluminum. For alloys of this class it is possible to use not only beta-elements that are isomorphous to titanium but also one of the eutectoid-forming beta-stabilizing elements as a beta-stabilizer because eutectoid decomposition of a small amount of beta-phase does not lead to a significant change in mechanical properties.

A large group of industrial alloys belong to the martensite class whose properties change over broad limits. In the annealed (stabilized) state their structure consists of 5-25% beta-phase and they have a $K_{\beta st} = 0.3-0.9$. Alloys of this class are distinguished by a good ration of strength and ductility in the annealed state. They can, to a larger or smaller degree, be strengthened by heat treatment, the effect of which grows with increased $K_{\beta st}$. Alloys of the martensite class are used in industry in both the annealed and thermally strengthened states. A shortcoming is increased structure sensitivity, especially in the thermally strengthened state. If they have been inadequately stabilized during heat treatment, their thermal stability can be lowered. Weld joints of these alloys, as a rule, must be heat treated.

Alloys of the transition class in a stable condition contain 25-50% beta-phase and during rapid cooling from the beta-region preserve the beta-structure which can, under certain conditions, undergo the beta-omega-transformation to some degree. These alloys encompass the concentration region of the alloys close to the critical composition having $K_{\beta st} = 1.0-1.4$

Alloys of the transition class have a good heterogeneous structure and a maximum effect of strengthening by heat treatment and can be annealed in large sections (200-250 mm) but are not as sensitive to structure as martensitic titanium alloys. Weld joints of transition titanium alloys require a mandatory heat treatment for restoring ductility. These alloys can be used in both the annealed and thermally strengthened states.

Pseudo-beta-titanium alloys are, in a stable state, a mixture of alpha- and beta-solid solutions with the significant advantage of the beta-phase ($K_{\beta st} = 1.6-2.8$). Pseudo-beta-alloys have good rollability, but are not as effectively strengthened by quenching and aging as alloys of the transition class although their strength can reach 140-150 kgf/mm² after such treatment. The distinguishing feature of these alloys is high ductility in the cold state. Immediately after welding the weld joint is unstable but has good ductility; in the case of use at elevated temperatures the weld joint should be annealed. VT15 and Ts6 pseudo-beta-alloys contain a large amount

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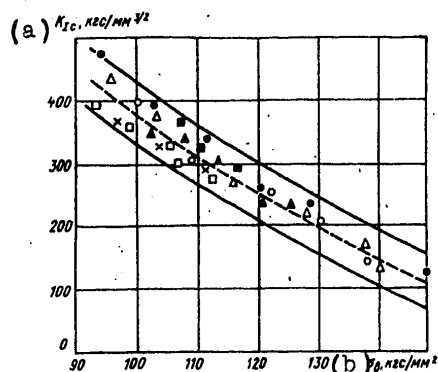
of eutectoid-forming element--chromium--and they do not belong to the alpha-beta-titanium alloys. They are distinguished by reduced thermal stability above 200°C, especially under load. VT32 pseudo-beta-alloy does not have this shortcoming since it is alloyed by isomorphous elements--molybdenum and vanadium.

The beta-alloys are very limited and as a structural material they do not yet have good practical applications. However, alloys of this type can be used for corrosion resistance (alloy 4200) and for short-time performance at high temperatures (1000-1200°C).

The mechanical properties of various titanium alloys in a thermally strengthened state in conjunction with actual technical conditions are presented in the table.

There exists the real possibility of further increasing the strength and heat resistance (up to 350°) of titanium alloys by a strengthening heat treatment--quenching followed by aging. However, although strength can be increased by the above treatment, all these alloys suffer a lowering of ductility, crack resistance as well as an increased sensitivity to stress concentrators (Fig. 6).

Fig. 6. Relationship between tensile strength and failure ductility of different titanium alloys with an alpha+beta-structure: o--VT22; Δ--VT14; ▲--VT3-1; □--VT6; ■--VT23; X--VT20; a-- K_{IC} , $\text{kgf}/\text{mm}^{3/2}$; b--tensile strength, kgf/mm^2 .



The interrelationship between tensile strength and failure ductility of thermally strengthened alpha+beta-alloys with a coarse grain (average grain diameter of 500-700 microns) is shown in Fig. 6. The overall tendency to lowering of failure ductility with increased strength of alpha+beta-titanium alloys is independent of their class.

The change in the characteristics of strengthening titanium alloys using VT22 alloy, as an example, with a fine (300 microns) and coarse (500 microns) grain is shown in Fig. 7.

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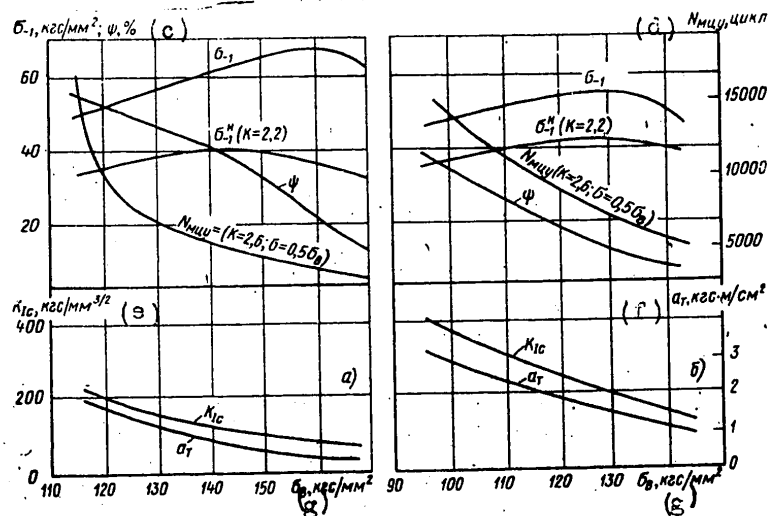


Fig. 7. Effect of tensile strength and structure after quenching and aging on the mechanical properties of VT22 alloy: a--grain diameter; b-- $D_{ave} = 500$ microns; c--reduction in area, %; d--number of cycles to failure; e--failure ductility, kgf/mm^2 ; impact strength, kgf-m/cm^2 ; f--tensile strength, kgf/mm^2 .

In an alloy with a fine-grain structure it is possible to produce higher values of tensile strength, fatigue strength of smooth samples and relative reduction in area. An alloy with a coarse grain with equal values of tensile strength is characterized by a higher resistance to failure.

The essential influence on the properties of titanium alloys turns out to be the intergranular structure.

Conclusion. Work on further increasing the strength, workability and ductility of titanium alloys must be directed to a more profound study of the possibility of thermal and

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thermomechanical treatments, use of the metastable structural state and intermetallide strengthening of alpha- and beta-solid solutions.

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MISCELLANEOUS

STRUCTURAL STRENGTH AT LOW TEMPERATURES

Kiev KONSTRUKSIONNAYA PROCHNOST' PRI NIZKIKH TEMPERATURAKH (Structural Strength at Low Temperatures) in Russian 1979

[Foreword and table of contents from book by Novikov, N. V.; Maystrenko, A. L., Ul'yanenko, A. P., Naukova dumka, 232 pages]

[Text] Foreword

The creation of cryogenic equipment is a new direction in machine building which has developed only in the last several decades. The most characteristic types of low temperature equipment are vessels operating under pressure at low temperatures, reservoirs and pipelines for storing and transporting liquefied gases--oxygen, nitrogen, hydrogen and helium, whose boiling temperatures are 90, 77, 20 and 4.2°K, respectively. Vessels of various capacities (up to 10^4 - 10^5 m³) are used more and more to transport and store liquefied natural gas (112°K), as well as petroleum products and various chemicals under low temperatures (up to 200°K).

The progress of cryogenic machine building is determined by reducing the loss of cold by improving the thermal insulation and reducing the amount of metal in the carrying structures. The latter corresponds to the basic trend in modern machine building that leads to the wider application of various kinds of thin-wall structural components. Excessively thick vessel walls, operating under pressure, make the structure more rigid and unyielding to temperature deformations, especially at transition sections. In this case, the thermal compensation deteriorates at the connections of metals with different moduli of elasticity, and the level of residual installation and welding stresses increases, as do the thermal stresses when temperatures change.

Thin-wall pressure vessels, reservoirs and pipes of the welded type for cryogenic liquids are among the machine building structures whose strength and operating reliability reserve for a given service life must be determined in a limited number of tests.

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Full-scale tests of cryogenic systems are difficult because the systems are unique from the safety technique standpoint, the possibilities of the technical base are limited, the cost of the products is high and it is necessary to carry out rapid construction and debugging. In this connection, there is the urgent determining of the carrying capacity of cryogenic equipment designs on the basis of tests of complex samples of their metals for a given variation of test conditions in accordance with a certain plan.

In this book, results are generalized of numerous tests of cryogenic equipment structural materials. They make it possible to evaluate and take into account the quantitative effect on the material strength of factors typical for the equipment being considered. An analysis of these data made it possible to derive regression equations that describe the structural strength of the considered group of materials that preserve their plasticity at low temperatures (cold plasticity). By using such equations, it is possible not only to approach the determination of the permitted loads on the design of a certain type in a substantiated way, but also to forecast its actual carrying capacity at operating cryogenic temperatures. In this case as reference data, test results on real facilities at relatively small cooling and usual temperatures near 300°K are used.

It should be noted that the effect of cooling on the structural strength of large structures cannot be reduced only to the change in the mechanical properties of materials.

Residual deformations are possible in thin-wall designs made of plastic materials with relatively low value of the yield limit (chrome-nickel austenitic steels and aluminum alloys) in the process of manufacturing, in transportation and in exploratory tests. Therefore, the problem of determining the shifts and distributions of stresses by calculations is complicated considerably by taking into account the special features of the deformation strengthening of the metals at various temperatures with respect to possible purely elastic solutions.

In evaluating and analyzing experimental data, it is impossible to use statistical methods unconditionally. With such an approach it is necessary to develop a certain physically substantiated model of low temperature strength of the considered group of materials. It is especially important to stress this in connection with a limited number of mechanical tests which may be made at helium (4.2°K) and hydrogen (20°K) temperatures.

Without a substantial model of a multifactor relationship of the structural strength, the strength reserve coefficient is represented by an exponentially decreasing function of the number of tests [84]. For example, when reducing the number of tests on a structure made of 12Kh18N10T steel, the initial value of the strength reserve coefficient, found from a great number of tests ($n \rightarrow \infty$) must be raised from 1.45 to 2.38 when the number of tests is reduced to $n=7$, to 3.13 for $n=5$ and to 4.28 when $n=4$ in order to provide for a constant norm value of faultless operation and an established confidence probability of destruction.

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To evaluate the structural strength of cryogenic equipment, it is important to consider the special features of the temperature-high speed relationship of the strength of cold-plastic metals at characteristic variations of the load values and the type of stressed condition. For a selected group of structural materials characteristic of cryogenic equipment, the following were considered and evaluated quantitatively: the effect of structural nonuniformity of the metal as a result of welding and machining, the effect of stress concentrators in the welded joint, and the effect of the type and mode of loading on the reduction of temperature strengthening of metal at cryogenic temperatures.

The determination of resistance to the origination and spreading of cracks, taking into account the effect of cryogenic cooling on the plasticity of metals of average strength--steels and aluminum alloys, is of great importance in evaluating the carrying capacity of thin-wall structures. The obtained experimental data made it possible to develop a method for evaluating the limiting condition of the structures by the relative change of the stress intensity coefficient, using the approach of linear destruction mechanics taking into account the effect of various factors on the development of plastic deformation in the zone of the through crack apex.

The determination of the multifactor relationship of structural strength in the form of a regression equation required checking the conditions of the possibility of using mathematical-statistical methods in the considered problem.

The cited complex of experimental data was used in the final result for substantiating the possibility of increasing the permissible stresses for cryogenic vessels and pipelines made of the considered metals and similar metals, while preserving the constant value of the safety coefficient in the 4.2 to 300°K temperature interval. To evaluate the possible consequences of the recommended changes in the permissible stresses, a safety criterion was used that takes into account the correlation relationship between structural-technological factors, force factors and cooling temperatures.

Increasing the permissible stresses for cryogenic vessels made of metals which are plastic at low temperatures makes it possible to reduce their weight considerably and obtain a considerable economic effect. Calculations show that increasing allowable stresses by 1 kg-force/mm² leads to a saving of 100,000 rubles in manufacturing steel vessels per each 2000 tons of liquid nitrogen and 1500 tons of liquid oxygen; when manufacturing aluminum--for each 240 tons of liquid hydrogen; when manufacturing titanium vessels--for each 38 tons of liquid hydrogen.

The data cited in this monograph were obtained mainly in the Material Strength Department of the Institute of Problems of Strength (IPP) of the UkrSSR Academy of Sciences. Moreover, domestic and foreign scientific-technological data were used, as well as results of work done jointly with

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staff members of the Electric Welding Institute imeni Ye. O. Paton of the UkrSSR Academy of Sciences and the "Kriogenmash" Scientific-Production Association.

The authors express their gratitude to the staff workers of the Institute of Problems of Strength, Ukrainian SSR for their participation in the many experiments and in processing the results presented in the monograph.

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